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TECHNICAL REPORT M-68-1

DYNAMICS OF WHEELED VEHICLES

Report 1

A MATHEMATICAL MODEL FOR THE TRAVERSAL OF RIGID OBSTACLES BY A PNEUMATIC TIRE

APPENDIX B: DIGITAL IMPLEMENTATION OF SEGMENTED TIRE MODEL

by

N. R. Murphy, Jr.

August 1969

Sponsored by

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Conducted by

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Foreword

The digital implementation of the segmented tire model is an extension of the study reported in the basic report and was developed at the U. S. Army Engineer Waterways Experiment Station (WES) as a part of the vehicle mobility research program under DA Project 1T062103A046, "Trafficability and Mobility Research," Task 03, "Mobility Fundamentals and Model Studies," sponsored by the Directorate of Development and Engineering, U. S. Army Materiel Command.

The study described herein was accomplished by personnel of the Vehicle Dynamics Section (VDS), Mobility Research Branch, Mobility and Environmental Division, under the general supervision of Messrs. W. G. Shockley and S. J. Knight, and under the direct supervision of Dr. D. R. Freitag and Mr. A. J. Green. Mr. N. R. Murphy, Jr., of the VDS and Mr. J. F. Smith of the Mathematics and Analysis Section, Electronic Computer Branch, wrote the computer programs. Mr. Murphy prepared this appendix.

COL Levi A. Brown, CE, was Director of WES during the preparation of this appendix. Mr. F. R. Brown was Technical Director.

Contents

Conversion Factors, British to Metric Units of Measurement

British units of measurement used in this report can be converted to metric units as follows:

Multiply	By	To Obtain
inches	2.54	centimeters
pounds	4.444	newtons
pounds per square inch	0.689476	newtons per square centimeter

Summary

This appendix presents the procedures for digital implementation of the segmented tire model, developed in the basic report for an analog computer. Two procedures are required: (a) determination of the segment spring coefficient from measured load-deflection test results, and (b) computation of the resultant force vector transmitted to the axle. Digital programs for both procedures were written in Fortran IV for a GE-420 system, and are included.

DYNAMICS OF WHEELED VEHICLES

A MATHEMATICAL MODEL FOR THE TRAVERSAL OF RIGID OBSTACLES BY A PNEUMATIC TIRE

APPENDIX B: DIGITAL IMPLEMENTATION OF SEGMENTED TIRE MODEL

1. For digital implementation of the segmented tire model, basically two procedures are required: (a) determination of the segment spring coefficient from measured load-deflection test results, and (b) computation of the resultant force vector transmitted to the axle. Therefore, two computer programs have been prepared.

Program 1

2. The first program (fig. B1) is used to compute the average deflection of each segment for a given vertical center-line deflection.* It is written in Fortran IV and programmed to run on a GE-420 system. The only input requirement is a card containing the tire radius in inches, the number of segments for 180 deg (current status of the program limits the maximum number of segments to 60), and the desired maximum vertical center-line deflection in inches multiplied by 10. This maximum deflection serves as a cutoff criterion for the computer and should be a number that does not exceed the tire section height. The actual maximum deflection is multiplied by 10 to ensure an integer value. This is a restriction imposed by the "DO-loop" that successively increments the center-line deflection.

3. A representative computer printout is shown in fig. B2 to illustrate the format of the output and to demonstrate, in conjunction with the following example, how the results are used to determine an appropriate segment spring coefficient:

---

* Appendix A to this report presents procedures for computing the necessary effective radial deflections.

a. Problem. A 9.00-14, 2-PR tire with a 14-in.* radius is inflated to 30-psi pressure; at this pressure it deflects 1 in. under a 760-lb load. Divide the lower half (180 deg) of the tire into 18 equal segments and determine the segment spring coefficient.

b. Solution. Prepare an input data card containing the tire radius in inches (14), the number of segments in 180 deg (18), and the maximum vertical center-line deflection in inches multiplied by 10 (say 3 × 10 = 30). Run, using the program in fig. B1. Since the coordinate (1.0, 760) was chosen from the load-deflection curve, examine the computer printout (fig. B2) and find the values of segment deflections for a center-line deflection of 1 in. Two segments on each side of the vertical center line are seen to be influenced at this particular deflection. Compute the segment spring coefficient K from the equation**

$$K = \frac{F}{2 \sum_{i=1}^{2} \Delta_i \cos \phi_i}$$

$$= \frac{760}{2(0.914 \cos 5^\circ + 0.384 \cos 15^\circ)}$$

$$= \frac{760}{2.56}$$

$$= 297 \text{ lb/in.}$$

This value is assigned as the spring coefficient for each segment and will change only if the number of segments or the inflation pressure is changed. Choosing a small deflection, such as 0.2 or 0.4 in., as a basis for determining the spring coefficient would most likely yield a K-value somewhat different from one with a larger value of deflection as a basis. Comparisons of measured load-deflection curves with those computed for K-values obtained from the segmented tire model at various deflections revealed that greater accuracy and consistency were obtained when K was computed from a deflection of 1 in. This deflection is generally in the area of maximum curvature on the load-deflection curve.

---

* A table of factors for converting British units of measurement to metric units is presented on page ix.

** See equation development in paragraph 21 of the main report.

Program 2

4. The second program (fig. B3) is used to compute the vertical and horizontal components of the resultant force vector transmitted to the axle. It, too, is written in Fortran IV for the GE-420 system. It is a complete, self-contained program that was assembled from a section of a more comprehensive one that represented a multidegree-of-freedom vehicle. Taken out of context, it contains none of the dynamics of the problem, i.e. the influence of the coupled differential equations describing the dynamics of the sprung mass of the system has been removed. Certain modifications were made regarding the input requirements, so the program demonstrates, in a static sense, how the components of the resultant wheel spring force are computed with the segmented tire concept. With other slight modifications, this program can be adapted as a subprogram to describe the tire compliance in other vehicle dynamics programs.

5. The solution is based on a purely geometric approach that treats each discrete axle movement interval in terms of space-oriented coordinates of the terrain and wheel center with respect to a fixed reference frame. The current program will handle up to 100 terrain profile points and up to 24 tire segments equally divided about a vertical axis through the axle of each wheel. Experience has indicated that twelve 10-deg segments, six on each side of the vertical, are sufficient to describe the tire compliance for most terrain conditions and obstacle configurations. The angle to each segment center line is measured from the vertical and is considered positive in a counterclockwise direction.

Computer calculations

6. The following sequence of calculations is used in this second program:

- a. Dimension the appropriate space for segment angles, segment spring coefficients, terrain profile points, segment forces, etc.
- b. Provide a "degree-to-radian" converter = $\pi/180$.
- c. Read in: Coordinates of wheel center (X1,Y1), tire radius, number of tire segments, number of terrain points, number of positions to be calculated, and X and Y increments.

d. Check for end of data; if no more data, exit computer.

e. Read in and store all segment angles, spring coefficients, and terrain points.

f. Print headings and terrain profile table.

g. Designate a variable name for the number of tire segments; e.g. NNN = NSEG.

h. Determine maximum horizontal projection of tire, i.e. XRET = X1 - WRAD, XFET = X1 + WRAD.

i. Initialize ITR = 2.

j. Change all segment angles from degrees to radians.

k. Compute the coordinates of each (undeflected) tire segment (i) location with respect to the wheel axle:

CX(i) = SIN(DSEG(i) *WRAD)
CY(i) = -COS(DSEG(i) *WRAD)

(These then remain constant for a given wheel.)

l. Set VVV(1) = 0 VVV(2) = 0.

m. Now determine the coordinates of each (undeflected) segment with respect to the fixed reference system, e.g.

RXY(1,i) = X1 + CX(i)
RXY(2,i) = Y1 + CY(i)

n. At this time compute intersections of the tire segment centers with terrain. For each tire segment:

(1) Set DMIN = 1.E10, i.e. some large number definitely greater than tire radius.

(2) Compute slope of tire segment (i), e.g. SM = CY(i)/CX(i).

(3) KTR = ITR. This is a counter to account for terrain stations.

(4) Set X2 = 0, i.e. first terrain point begins at X = 0.

(5) Recall Y2 from proper storage location; now there is terrain coordinate X2,Y2.

(6) Recall X3,Y3, i.e. the next forward terrain coordinate.

(7) Obtain the slope of this line (terrain segment).

(8) Compare it with the slope of i^{th} tire segment.

(9) If slopes are not the same, the lines will intersect; use the point slope method to obtain coordinate of intersection, i.e. XX,YY for i^{th} tire segment. (This is

coordinate of deflected tire segment with respect to fixed reference system.)

(10) Now determine whether this coordinate falls within the tire circumference.

(11) If not, then increment the terrain segment and recheck as before until a coordinate is determined that falls within the tire circumference.

(12) Compute the radial distance of this intersection from the wheel center and set this distance equal to the variable, DMIN. This represents a new "minimum" length.

(13) Check this length against last minimum value.

(14) If it is smaller, let the coordinates of this deflected tire segment be: RXY(1,i) = XX; RXY(2,i) = YY.

(15) If, however, it is larger, check to see whether forward edge of tire is ahead of the terrain station.

(16) If so, then advance the station by one. Go back to step (1).

(17) If not, go to next tire segment and repeat the procedures described above until all intersections of tire segment centers with terrain segments have been computed.

This operation should locate the positions (with respect to the fixed and moving reference) of each deflected tire segment.

o. Now compute the actual deflection of each tire segment beginning as follows:

RXY(1,i) = X1 - RXY(1,i)
RXY(2,i) = Y1 - RXY(2,i)

These are vertical and horizontal components of new segment length.

p. Store these values in a temporary storage AA(1),AA(2).

q. Compute the radial distance of each segment using the Pythagorean Theorem, i.e. TMAG(i) = square root of sum of squares of the respective components.

r. Obtain the sin and cos of each segment angle as follows:

RXY(1,i) = AA(1)/TMAG(i) = sin of the segment angle
RXY(2,i) = AA(2)/TMAG(i) = cos of the segment angle

s. Compute the radial force in each segment, i.e.

$$TMAG(i) = (WRAD - TMAG(i)) * SEGK(i) = K\delta$$

where δ = WRAD - TMAG(i)

t. Compute the horizontal and vertical components of the resultant force vector, e.g.

$$VVV(1) = \Sigma TMAG(i) * RXY(1,i) \rightarrow \text{horizontal component}$$
$$VVV(2) = \Sigma TMAG(i) * RXY(2,i) \rightarrow \text{vertical component}$$

u. Print results.

v. Increment tire center position and repeat procedures.

7. Computation of resultant tire spring force vector is summarized as follows:

a. The points where all tire segment centers (spring locations) intersect the undeflected tire circumference are located.

b. The points where tire segment centers intersect the terrain are located.

c. The radial reduction in length of each tire segment center intersecting the terrain is computed.

d. The force vector for each segment is computed using the displacement of the segment center and the segment spring coefficient.

e. The segment force vectors are summed to yield the vertical and horizontal components of the resultant spring force vector for the wheel.

Notation

8. Symbols used in the second program are defined below:

CX,CY	Coordinates (with respect to the wheel axle) of points where segment center lines intersect the undeflected tire circumference
DSEG	Segment angle in degrees; the angle measured from a vertical line through the wheel axle to center line of segment (positive value, counterclockwise)
DTR	Degree-to-radian conversion factor
HGT	Elevation of profile
NPOS	Number of wheel positions to be computed
NSEG,NNN	Number of tire segments
NTP	Number of terrain points to be used

RXY	Absolute coordinates (with respect to fixed X-Y reference) of the points where segment center lines intersect the undeflected tire circumference
SEGK	Segment spring coefficient (can vary with each segment)
ST	Slope of a terrain segment
STA	Horizontal distance of terrain profile
TMAG	Radial force of segment
VVV(1)	Horizontal component of force
VVV(2)	Vertical component of force
WRAD	Wheel radius
XX,YY	Absolute coordinates of the intersection points of the terrain with tire segment
X1,Y1	Coordinates of wheel center
X2,Y2	Absolute coordinates of the rear terrain station
X3,Y3	Absolute coordinates of the adjacent terrain station in increasing X-direction
XFET,XRET	Forward and rear extremes of tire (horizontal)
XINCR,YINCR	Increment of axle movement of wheel in X- and Y-directions

Summary

9. The required input information for the second program consists of (a) the coordinates of the tire center, (b) the undeflected tire radius, (c) the number of segments to be used, (d) the number of terrain coordinates, (e) the number of axle positions to be calculated, (f) the X- and Y-increments (i.e. the movements of the axle), (g) each segment angle in degrees, (h) each segment spring constant (may be different for each segment if desired), and (i) the terrain profile coordinates. The tire-center coordinates are the only inputs that do not remain constant. When the program is used in an appropriate vehicle dynamics program that describes the motions of the sprung masses, these coordinates are determined at each time step by the differential equations that describe the dynamics of the vehicle system. The coordinates (X1,Y1) of the tire center are used to compute forward and rear extremes of the tire for each increment of movement. This is accomplished by subtracting or adding the tire radius (WRAD) to the coordinate X1. (See fig. B4.) The program can then be used to compute

the location of the points, relative to the axle, where each segment center intersects the tire circumference. These values never change and are stored in the computer under the identification CX(i) and CY(i).

10. Then for each increment of horizontal axle movement (XINCR), the program proceeds as follows:

> The points of the wheel at each segment's center line are located relative to the fixed (X-Y) reference frame and stored as coordinates under the identification RXY(1,i) and RXY(2,i). This gives the complete orientation of each undeflected segment "spring." The program then proceeds into a loop that calculates the intersections of the segment center lines and the terrain profile segments, which are constructed from straight-line connections of the terrain profile points. These intersections are determined by the point-slope method, which compares the slopes of each segment center line (proceeding in a counterclockwise sequence beginning with the rear segment) with the slopes of each terrain segment within the forward extreme of the tire. A check is made in each instance to determine if the intersections occur within the periphery of the undeflected tire. This indicates whether a particular segment is influenced by the terrain and the amount that each segment deflects in a radial direction. The radial deflection that is computed for each segment spring is multiplied by the appropriate spring constant to yield a segment force vector whose magnitude and orientation are known. These individual vectors are summed to yield the vertical and horizontal components of the resultant force vector acting at the axle. The axle is then advanced to the next position and the process is repeated.

Damping

11. No provision has been made to incorporate segment damping forces at this time. The influence of tire damping is currently computed as a gross vertical force from the relative motion between the axle and a point directly beneath the axle.

A


```
C     A PROGRAM TO COMPUTE AVG DEFLECTIONS OF PNEUMATIC TIRE SEGMENTS
      DIMENSION AVGDEL(60)
      TANF (AZ) = SIN  (AZ)/ COS (AZ)
      PI = 3.1416
    1 READ 10, R, N, IDEFL
       PRINT 155
   40 PRINT 60
C     R IS TIRE RADIUS IN IN., N IS NO. OF SEGMENTS FOR 180 DEGREES
C     IDEFL IS MAX. VERTICAL DEFLECTION AT VRP IN IN. TIMES 10
      THETA = PI/N
      W = R * THETA
      TTHETA = THETA * 180.0/PI
      DO 15 J = 1, IDEFL
      DELTA =  J/10.
C     DELTA IS CENTERLINE DEFLECTION IN IN.
      X = SQRT  (2 * R * DELTA - DELTA * DELTA)
      PHI = ATAN2 ( X, R - DELTA)
C     ARC IS ARC OF CONTACT,  W IS ARC OF ENTIRE SEGMENT
      B = PHI/THETA
      IF (B - 1.0) 5, 6, 6
    5 M = 1
      I = 1
      ARC = R * PHI
C     M IS THE NO. OF SEGMENTS INFLUENCED BY DELTA DEFLECTION
      AVGDEL(I) = R- SQRT  ((W - ARC)/W * R * R + R/W *((R - DELTA)
     1 **2)*(TANF(PHI)))
C     AVGDEL   IS AVG DEFLECTION OF SEGMENT
      GO TO 14
    6 K = B
C         NO. OF SEGMENTS FULLY DEPRESSED
      IF (B - K) 3,8,7
C          IS B AN INTEGER
    3 STOP 55
    7 M =B + 1.0
      GO TO 9
    8 M = B
    9 DO 4 I = 1, K
    4 AVGDEL(I)    = R - SQRT  (R/W*((R-DELTA)**2)*(TANF(I*THETA)
     1 - TANF((I - 1) * THETA)))
      IF (M-B) 11, 13, 11
   13 IF(I-14) 14, 14, 17
   11 I = M
        ARC = R * PHI - (I - 1) * W
      AVGDEL(I)    = R - SQRT  ((W - ARC)/W * R * R +(R/W *((R - DELTA)
     1  **2) *(TANF(PHI)-TANF((I-1)*THETA ))))
      IF(I-14) 14, 14, 17
   14 PRINT 185
      PRINT 186
      PRINT 187, DELTA, N, TTHETA, (AVGDEL(I),   I=1, M)
      GO TO 15
   17 PRINT 185
      PRINT 186
      PRINT 188, DELTA, N, TTHETA, (AVGDEL(I),   I= 1, 14)
      PRINT 189
      PRINT 190, (AVGDEL(I),   I=15, M)
   15 CONTINUE
      GO TO 1
   10 FORMAT (F10.2,2I5)
  155 FORMAT (1H1)
   60 FORMAT (41X, 34HCOMPUTATION OF AVERAGE DEFLECTIONS//)
```

```
      ARC = R * PHI
C     M IS THE NO. OF SEGMENTS INFLUENCED BY DELTA DEFLECTION
      AVGDEL(I) = R- SQRT  ((W - ARC)/W * R * R + R/W *((R - DELTA)
     1 **2)*(TANF(PHI)))
C     AVGDEL   IS AVG DEFLECTION OF SEGMENT
      GO TO 14
    6 K = B
C        NO. OF SEGMENTS FULLY DEPRESSED
      IF (B - K) 3,8,7
C          IS B AN INTEGER
    3 STOP 55
    7 M =B + 1.0
      GO TO 9
    8 M = B
    9 DO 4 I = 1, K
    4 AVGDEL(I)    = R - SQRT  (R/W*((R-DELTA)**2)*(TANF(I*THETA)
     1 - TANF((I - 1) * THETA)))
      IF (M-B) 11, 13, 11
   13 IF(I-14) 14, 14, 17
   11 I = M
        ARC = R * PHI - (I - 1) * W
      AVGDEL(I)    = R - SQRT  ((W - ARC)/W * R * R +(R/W *((R - DELTA)
     1  **2) *(TANF(PHI)-TANF((I-1)*THETA ))))
      IF(I-14) 14, 14, 17
   14 PRINT 185
      PRINT 186
      PRINT 187, DELTA, N, TTHETA, (AVGDEL(I),   I=1, M)
      GO TO 15
   17 PRINT 185
      PRINT 186
      PRINT 188, DELTA, N, TTHETA, (AVGDEL(I),   I= 1, 14)
      PRINT 189
      PRINT 190, (AVGDEL(I),   I=15, M)
   15 CONTINUE
      GO TO 1
   10 FORMAT (F10.2,2I5)
  155 FORMAT (1H1)
   60 FORMAT (41X, 34HCOMPUTATION OF AVERAGE DEFLECTIONS//)
  185 FORMAT (3X, 2HCL, 3X, 2HNO, 3X, 5HTHETA, 18X, 7HAVERAGE, 2X
     1 7HSEGMENT, 2X,10HDEFLECTION, 2X, 2HIN,  2X, 6HINCHES)
  186 FORMAT(2X, 4HDEFL, 2X, 3HSEG, 3X, 3HDEG, 3X, 4HSEG1, 3X, 4HSEG2,
     1 3X, 4HSEG3, 3X, 4HSEG4, 3X, 4HSEG5, 3X, 4HSEG6, 3X, 4HSEG7,
     1 3X, 4HSEG8, 3X, 4HSEG9,  2X, 5HSEG10,  2X, 5HSEG11, 2X, 5HSEG12,
     1 2X, 5HSEG13,  2X,  5HSEG14)
  187 FORMAT (F6.2, I5, F6.2, 14F7.3/)
  188 FORMAT (F6.2, I5, F6.2, 14F7.3/)
  189 FORMAT(19X, 5HSEG15, 2X, 5HSEG16, 2X, 5HSEG17, 2X, 5HSEG18,
     1 2X, 5HSEG19, 2X, 5HSEG20, 2X, 5HSEG21, 2X, 5HSEG22, 2X, 5HSEG23,
     1 2X, 5HSEG24, 2X, 5HSEG25, 2X, 5HSEG26, 2X, 5HSEG27, 2X, 5HSEG28)
  190 FORMAT (17X, 14F7.3/)
      END
```

Fig. B1. Program for computing average deflections of pneumatic tire segments

B

A

COMPUTATION OF AVERAGE DEFLECTIONS

CL DEFL	NO SEG	THETA DEG	SEG1	SEG2	SEG3	SEG4	SEG5	SEG6	SEG7	SEG8	SEG9	SEG10	SEG11	SEG12	SEG13	SEG14
0.10	18	10.00	0.041													
0.20	18	10.00	0.115													
0.30	18	10.00	0.210	0.001												
0.40	18	10.00	0.311	0.015												
0.50	18	10.00	0.411	0.044												
0.60	18	10.00	0.512	0.068												
0.70	18	10.00	0.612	0.145												
0.80	18	10.00	0.713	0.213												
0.90	18	10.00	0.813	0.293												
1.00	18	10.00	0.914	0.384												
1.10	18	10.00	1.014	0.485	0.000											
1.20	18	10.00	1.115	0.589	0.008											
1.30	18	10.00	1.216	0.692	0.025											
1.40	18	10.00	1.316	0.796	0.052											
1.50	18	10.00	1.417	0.900	0.087											
1.60	18	10.00	1.517	1.003	0.131											
1.70	18	10.00	1.618	1.107	0.183											
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]											

CL DEFL	NO SEG	THETA DEG	SEG1	SEG2	SEG3	SEG4	SEG5	SEG6	SEG7	SEG8	SEG9	SEG10	SEG11	SEG12	SEG13	SEG14
1.30	18	10.00	1.216	0.692	0.025											
1.40	18	10.00	1.316	0.796	0.052											
1.50	18	10.00	1.417	0.900	0.087											
1.60	18	10.00	1.517	1.003	0.131											
1.70	18	10.00	1.618	1.107	0.183											
1.80	18	10.00	1.718	1.211	0.243											
1.90	18	10.00	1.819	1.314	0.312											
2.00	18	10.00	1.919	1.418	0.389											
2.10	18	10.00	2.020	1.522	0.474											
2.20	18	10.00	2.120	1.625	0.566											
2.30	18	10.00	2.221	1.729	0.665											
2.40	18	10.00	2.321	1.833	0.774	0.000										
2.50	18	10.00	2.422	1.936	0.885	0.005										
2.60	18	10.00	2.522	2.040	0.995	0.017										
2.70	18	10.00	2.623	2.144	1.106	0.037										
2.80	18	10.00	2.723	2.248	1.217	0.063										
2.90	18	10.00	2.824	2.351	1.327	0.097										
3.00	18	10.00	2.924	2.455	1.438	0.137										

Fig. B2. Printout of computations of average deflections

A


```
$        TITLE    INGRAM   TC1   04-G2-RO-010   7 FEBRUARY 1969
C       THIS CODE WAS TAKEN FROM A VEHICLE DYNAMICS PROGRAM WHICH IS NOW
C       BEING USED AT WES,
C       THE PROGRAM PRESENTED HERE CONTAINS NONE OF THE DYNAMICS OF THE
C       PROBLEM, BUT IS INTENDED ONLY TO DEMONSTRATE STATICALLY HOW THE
C       RESULTANT WHEEL SPRING FORCE IS COMPUTED USING THE SEGMENTED WHEEL
C       CONCEPT.
        DIMENSION DSEG(24), SEGK(24),STA(100),HGT(100),TMAG(24),RXY(2,24)
        DIMENSION  VVV(2),AA(2),CX(24), CY(24)
      1 FORMAT ( 8F10.0 )
        DTR = 3.141592653 / 180.
C       THE ANGLE,DSEG(I), TO EACH SEGMENT CENTER IS MEASURED FROM THE
C       VERTICAL, POSITIVE COUNTERCLOCKWISE IN DEGREES.
C       UNITS FOR OTHER VARIABLES ARE ARBITRARY, BUT SHOULD BE CONSISTENT,
    100 READ 1, X1, Y1,WRAD, NSEG, NTP,NPOS, XINCR,YINCR
        CALL EOFTST(50,ITEST)
        GO TO(120,110),ITEST
    110 CALL EXIT
    120 READ 1, ( DSEG(I), SEGK(I), I = 1,NSEG )
        READ 1, ( STA(I), HGT(I), I = 1, NTP )
        PRINT 3,        WRAD,NSEG
      3 FORMAT(
       115H1WHEEL RADIUS = F8.2, //
       221H NUMBER OF SEGMENTS = I5//)
        PRINT 4 ,( I,DSEG(I),SEGK(I), I=1,NSEG )
      4 FORMAT (34H SEGMENT      ANGLE TO        SPRING     /
       1        36H NUMBER       CENTERLINE      CONSTANT  //
       2     (        I5,             F15.2,         F14.2  )    )
        PRINT 5 ,(STA(I),HGT(I),I = 1,NTP )
      5 FORMAT ( 16HOTERRAIN PROFILE /
       1         16H      X         Y     /
       2      ( 2F8.2 )                  )
        NNN = NSEG
        XRET =   X1 - WF.D
        XFET =   X1 + WRAD
        ITR = 2
        DO 1065  I = 1,NSEG
        DSEG(I) = DSEG(I) * DTR
        CX(I) = SIN(DSEG(I)) * WRAD
        CY(I)=-COS(DSEG(I))*WRAD
   1065 CONTINUE
        PRINT 10
     10 FORMAT(50HOLOCATION OF WHEEL CENTER          RESULTANT FORCES /
       1  7X,1HX,9X,1HY,17X,4HF(X),6X,4HF(Y)       )
        DO 200 II=1,NPOS
        VVV(1)=0.                                                         7372
        VVV(2)=0.                                                         7373
C       ...LOCATE ALL POINTS ALONG TIRE CIRCUMFERENCE                     765
        DO 5325 I=1,NNN                                                   766
        RXY(1,I) = X1 + CX(I)
        RXY(2,I) = Y1 + CY(I)
   5325 CONTINUE                                                          769
C       ...INTERSECT SEGMENT CENTERS WITH TERRAIN                         770
        DO 5350 I=1,NNN                                                   771
        DMIN =1.E10
        SM= CY(I)     / CX(I'
```

```
      RXY(2,I) = Y1 + CY(I)
 5325 CONTINUE                                                   769
C     ..,INTERSECT SEGMENT CENTERS WITH TERRAIN                  770
      DO 5350 I=1,NNN                                            771
      DMIN =1.E10
      SM= CY(I)     / CX(I)
      KTR=ITR                                                    773
      X2=0.                                                      774
      Y2=HGT(KTR-1)                                              775
 5329 CONTINUE                                                   776
      X3=STA(KTR)-  STA(ITR-1)                                   777
      Y3=HGT(KTR)                                                778
      ST=(Y2-Y3)/(X2-X3)                                         779
      IF(SM-ST)5331,5330,5331                                    780
 5330 XX=1.E35                                                   781
      GO TO 5333                                                 782
 5331 XX=(Y2-Y1+SM*X1-ST*X2)/(SM-ST)                             783
 5333 YY= ST* (XX-X2) + Y2                                       784
      KERR=KBTWN(X2,XX,X3)                                       785
      GO TO (5332,5336),KERR                                     786
 5332 KERS=KBTWN(Y2,YY,Y3)                                       787
      GO TO (5334,5336),KERS                                     7871
 5334 KERT=KBTWN(X1,XX,RXY(1,I))                                 7872
      GO TO (5335,5336),KERT                                     7873
 5335 KERU=KBTWN(Y1,YY,RXY(2,I))                                 7874
      GO TO (5340,5336),KERU                                     7875
 5336 IF(XFET-STA(KTR))5350,5350,5338                            7876
 5338 KTR=KTR+1                                                  7877
      X2=X3                                                      788
      Y2=Y3                                                      789
      GO TO 5329                                                 790
 5340 DMIN1=SQRT((XX-X1)**2+(YY-Y1)**2)
      IF(DMIN1-DMIN)5341,5341,5336
 5341 DMIN=DMIN1
      RXY(1,I)=XX
      RXY(2,I)=YY                                                792
      GO TO5336
 5350 CONTINUE                                                   793
 5355 CONTINUE                                                   794
C                                                                795
      DO 5356 I=1,NNN                                            796
      RXY(1,I)=X1-RXY(1,I)
      RXY(2,I)=Y1-RXY(2,I)
 5356 CONTINUE                                                   799
C     ..,NORMALIZE RXY AND LET TMAG BE MAGNITUDE                 800
      DO 5357 I=1,NNN                                            801
      AA(1)=RXY(1,I)                                             802
      AA(2)=RXY(2,I)                                             803
      TMAG(I)=SQRT (AA(1)*AA(1) +AA(2)*AA(2))                    804
      RXY(1,I)=AA(1)/TMAG(I)                                     805
      RXY(2,I)=AA(2)/TMAG(I)                                     806
 5357 CONTINUE                                                   807
C     ..,COMPUTE FORCE FOR EACH SEGMENT                          808
      DO 5358 I=1,NNN                                            809
      TMAG(I)=(WRAD-TMAG(I))* SEGK(I)
 5358 CONTINUE                                                   811
C     ..,COMPUTE COMPOSITE FORCE VECTOR                          812
      DO 5359 I=1,NNN                                            813
      VVV(1)=VVV(1) + TMAG(I)*RXY(1,I)
      VVV(2)=VVV(2) + TMAG(I)*RXY(2,I)
 5359 CONTINUE
      PRINT 2,X1,Y1,VVV
    2 FORMAT(2F10.2,10X,2F10.2)
      Y1=Y1+YINCR
      X1=X1+XINCR
  200 CONTINUE
      GO TO 100
      END
```

B

```
      GO TO 5336
 5350 CONTINUE
 5355 CONTINUE
C
      DO 5356 I=1,NNN
      RXY(1,I)=X1-RXY(1,I)
      RXY(2,I)=Y1-RXY(2,I)
 5356 CONTINUE
C     ...NORMALIZE RXY AND LET TMAG BE MAGNITUDE
      DO 5357 I=1,NNN
      AA(1)=RXY(1,I)
      AA(2)=RXY(2,I)
      TMAG(I)=SQRT (AA(1)*AA(1) +AA(2)*AA(2))
      RXY(1,I)=AA(1)/TMAG(I)
      RXY(2,I)=AA(2)/TMAG(I)
 5357 CONTINUE
C     ...COMPUTE FORCE FOR EACH SEGMENT
      DO 5358 I=1,NNN
      TMAG(I)=(WRAD-TMAG(I))* SEGK(I)
 5358 CONTINUE
C     ...COMPUTE COMPOSITE FORCE VECTOR
      DO 5359 I=1,NNN
      VVV(1)=VVV(1) + TMAG(I)*RXY(1,I)
      VVV(2)=VVV(2) + TMAG(I)*RXY(2,I)
 5359 CONTINUE
      PRINT 2,X1,Y1,VVV
    2 FORMAT(2F10.2,10X,2F10.2)
      Y1=Y1+YINCR
      X1=X1+XINCR
  200 CONTINUE
      GO TO 100
      END
```

```
06/30/69    OKBTWNF@    INGRAM  TC1  04-G2-R0-010  7 FEBRUARY 19  FUNCTION   PAGE #   1    KBTW  SDL6

      FUNCTION KBTWN(A,P,B)
      IF(A-P)30,40,20
   20 IF(B-P)40,40,50
C     IS P BETWEEN A AND B
   30 IF(B-P)50,40,40
C     VALID RETURN
   40 KBTWN = 1
      RETURN
C     INVALID RETURN
   50 KBTWN = 2
      RETURN
      END
```

Fig. B3. Program for computing vertical and horizontal components of the resultant force vector transmitted to the axle

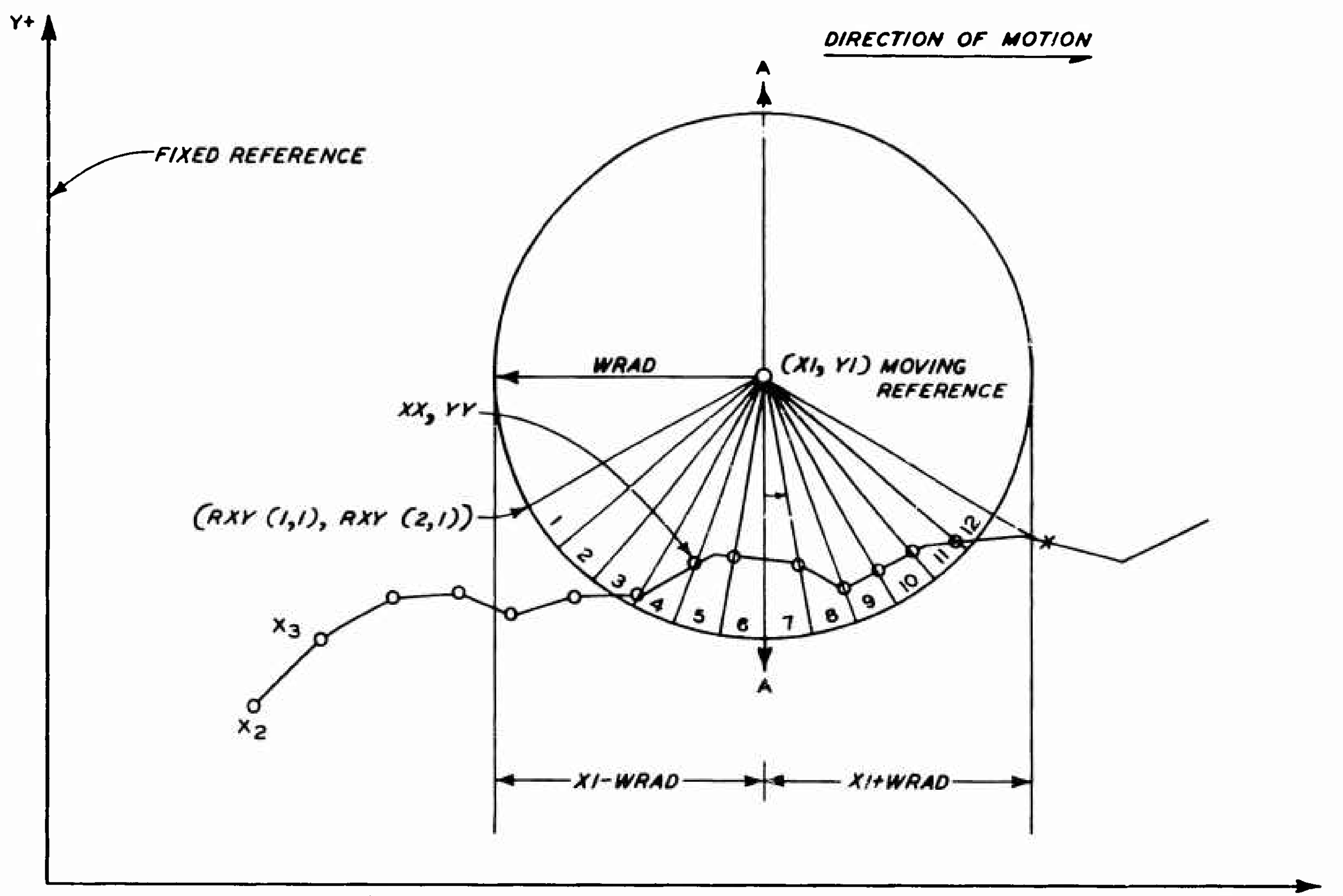

Fig. B4. Schematic diagram depicting space coordinates of digital segmented tire program

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13. ABSTRACT

This appendix presents the procedures for digital implementation of the segmented tire model, developed in the basic report for an analog computer. Two procedures are required: (a) determination of the segment spring coefficient from measured load-deflection test results, and (b) computation of the resultant force vector transmitted to the axle. Digital programs for both procedures were written in Fortran IV for a GE-420 system, and are included. ( )

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